2019 SECED Conference
Earthquake risk and engineering towards a resilient world
9-10 September 2019, Greenwich, London

A SEISMIC RISK REDUCTION STRATEGY FOR THE KYRGYZ REPUBLIC

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Abstract: *The Kyrgyz Republic in Central Asia is located in a region of high seismicity and has suffered significant past earthquake losses. Two recent examples are the 1992 Suusamyr earthquake (Mw=7.2) and the 2008 Nura earthquake (Mw=6.6), which killed approximately 3% and 8% of the nearby settlement populations respectively. There is a clear awareness of the risk that earthquakes pose in the Kyrgyz Republic, and over the past decade the government and other stakeholders have accelerated their efforts to reduce this risk. In 2015, the World Bank commissioned a study, on behalf of the Kyrgyz Government, to provide a countrywide seismic hazard and risk assessment and to propose a comprehensive seismic risk reduction strategy. In this paper we summarise the methodology and results of the seismic risk assessment, and describe the seismic risk reduction strategy and recommendations, which are in line with the 2015 Sendai Framework. In addition to providing quantitative seismic risk results for the entire country, the study's cost benefit analyses gave evidence to justify a new geographic focus for investment (the Ferghana Valley, in addition to the capital city Bishkek). The strategy included recommendations for physical measures such as prioritized reconstruction and retrofitting as well as recommendations related to the institutional and regulatory environment, disaster risk financing and the insurance sector. To communicate the work and translate it into practical risk reduction policy, the strategy integrated the state-of the-art quantitative risk results into a wider framework of appropriate recommendations tailored for government, local institutions and community stakeholders.*

Introduction

The Kyrgyz Republic is a landlocked country in Central Asia with a population of approximately 6 billion and a GDP of 7.6 billion USD in 2018 (World Bank, 2019a). It is located in a highly seismic region and, in addition, the country's predominantly mountainous terrain and climate make it vulnerable to a range of other natural hazards such as landslides, rockfall, avalanches and flooding. Although earthquakes occur less frequently than other natural hazards, they cause the largest proportion of disaster related losses across the country (World Bank, 2008). Due to its developing economy and ongoing rapid urbanization, there is a strong incentive to invest in seismic risk reduction as the most effective way to mitigate the potential impact of disaster related shocks and reduce expected losses.

There has long been an awareness of natural disaster risk including seismic risk in the Kyrgyz Republic, and there have been ongoing efforts by the government and other stakeholders to reduce the risk (UNISDR, 2010). To build upon these efforts, in 2015 a study was commissioned by the Global Facility for Disaster Reduction and Recovery (GFDRR) and the World Bank on behalf of the government of the Kyrgyz Republic, to provide a countrywide seismic hazard and risk assessment, and to propose a comprehensive seismic risk reduction strategy. In this paper we describe the development of the risk reduction strategy and present key recommendations

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and outputs. The paper is organised as follows: first, a summary is provided of the quantitative seismic hazard and risk assessment and cost benefit analysis results which informed the strategy. Then, the methodology for the risk reduction strategy is described as well as the institutional, regulatory and financial context for risk reduction implementation. Finally, key recommendations of the strategy are summarised along with recommendations for future developments.

Summary of the seismic hazard and risk assessment

In this section, a brief overview of the seismic hazard and risk assessment is presented. A more detailed description of the methodology and results can be found in Free et al. (2018a; 2018b), Free et al. (2019) and the full project reports (Arup, 2016a; Arup, 2017a).

Seismic Hazard Assessment

As part of the quantitative seismic risk assessment, seismic hazard assessment was performed using the OpenQuake engine (OQ-engine, Silva et al., 2014). Both scenario-based assessments, where multiple representative earthquake scenarios are selected and simulated, as well as a countrywide probabilistic seismic hazard assessment (PSHA) were performed. The scenario earthquakes were selected based on the mapped location and available seismological properties of known active faults across the country in close proximity to population centres. The PSHA involved defining a seismic source model (building upon the work of Ullah, 2015 and references therein), a selection of ground motion prediction equations (GMPEs), and a description of the near-surface geological conditions (i.e., to take into account to some degree site effects).

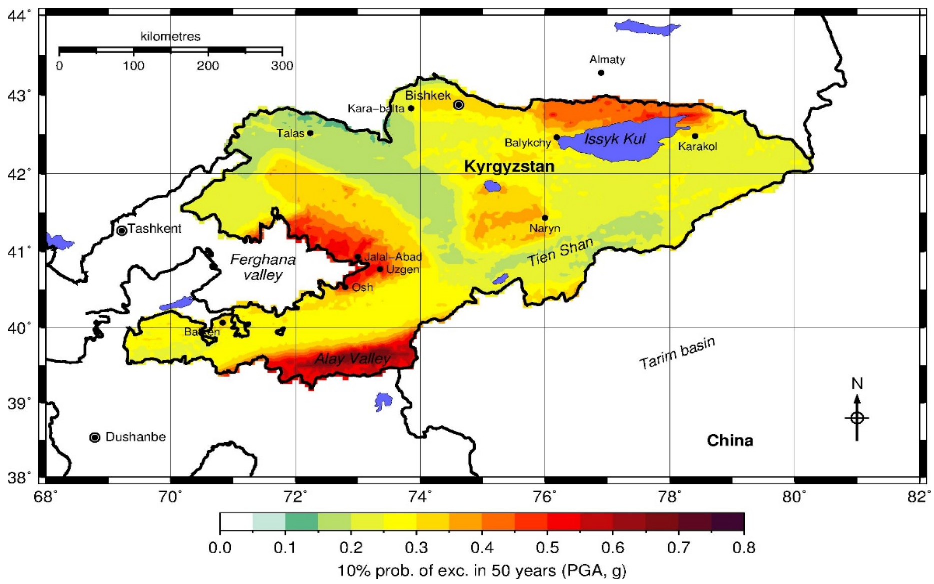

Figure 1 Probabilistic seismic hazard map for the Kyrgyz Republic in terms of peak ground acceleration (PGA) with a 10% probability of being exceeded over 50 years with a non-uniform Vs30 assumption from USGS.

Selected results for a USGS Vs30 near-surface assumption are presented in Figure 1 for peak ground accelerations with a return period of 475 years. To capture the uncertainty for the ground conditions, the seismic hazard assessment was also performed assuming bedrock and a soft soil condition (Arup, 2016a). The most obvious features are the higher levels of hazard north of Lake Issyk Kul to the southwest in the vicinity of the Ferghana Valley, one of the most heavily populated regions of Central Asia, and the south around the Alai Valley near the border with Tajikistan. An area of heightened hazard can be also seen in the centre of the country, in the vicinity of the town of Naryn. For this map, the highest hazard is predicted to be around the Alai Valley (in the range of 0.6 to 0.7 g), with the lowest being southwest of Bishkek and southeast of Talas (in the range of 0.1 to 0.2 g).

Seismic Risk Assessment

For the seismic risk assessment, losses were independently evaluated for each asset portfolio by using tailored exposure and vulnerability models specific to the characteristics of each group of assets. Representative building and linear infrastructure (roads and bridges) construction typologies were developed based on in-country rapid field surveys and past studies for the region (Arup, 2017a). As there was variable quality in the data for each asset type, tailored exposure models were developed for each category. The exposure modelling approach combined different data sources and acquisition techniques and used data obtained at different scales in order to infer relevant information (e.g., construction type, building area and number of floors, primary or secondary linear infrastructure) (Wieland et al., 2015; Arup 2017a; Pittore et al., 2019). At the regional scale, global geospatial datasets and local expert knowledge were combined. The European Macroseismic Scale (EMS-98), proposed by Grünthal (1998), was used to characterize estimated structural and non-structural damage of the building portfolios. The vulnerability index approach (Gulkan et al., 1992; SYNER-G, 2013) was used to develop fragility and vulnerability models, in combination with the consequence model of Mouroux (2004; 2006) for each building typology. In the absence of local data and regional models, the methodology proposed by HAZUS (FEMA, 2003) was adopted for the social vulnerability model. The exposure models for roads and bridges were derived from the OpenStreetMap database and validated with high resolution remote-sensing imagery provided by Bing and Google Maps. Damage states and fragility functions for the road and bridge typologies were obtained from the SYNER-G project (SYNER-G, 2013) and the damage to loss ratios from FEMA (2003) were adopted. Replacement and retrofitting cost estimates were made based on a combination of international and in-country data following the GEM methodology (GEM, 2013; Arup, 2016b). All seismic risk calculations for this project were undertaken using the GEM OpenQuake Engine. Two methods were used to evaluate losses: scenario earthquake risk assessments for each scenario, and time-based probabilistic earthquake risk assessment that account for all the events that may occur in the future, as well as their probability of occurrence. Losses evaluated include the expected number and range of fatalities, direct economic losses (in 2015 USD), number of building collapses and expected damage to infrastructure (roads and bridges).

Selected Results

The results of the probabilistic seismic risk assessment showed that the Kyrgyz Republic is exposed to a severe level of seismic risk, with expected annual losses (EALs) associated with direct damage to buildings exceeding 280 million USD – over 4% of GDP – and expected annual fatalities of up to several hundred. In the case of 475-year return period losses (i.e. loss level that has 10% probability of being exceeded over a period of 50 years), potential economic losses are estimated at up to 6.4 billion USD (almost 100% of GDP) and up to 4,400 fatalities, for residential buildings alone (Free et al, 2018a).

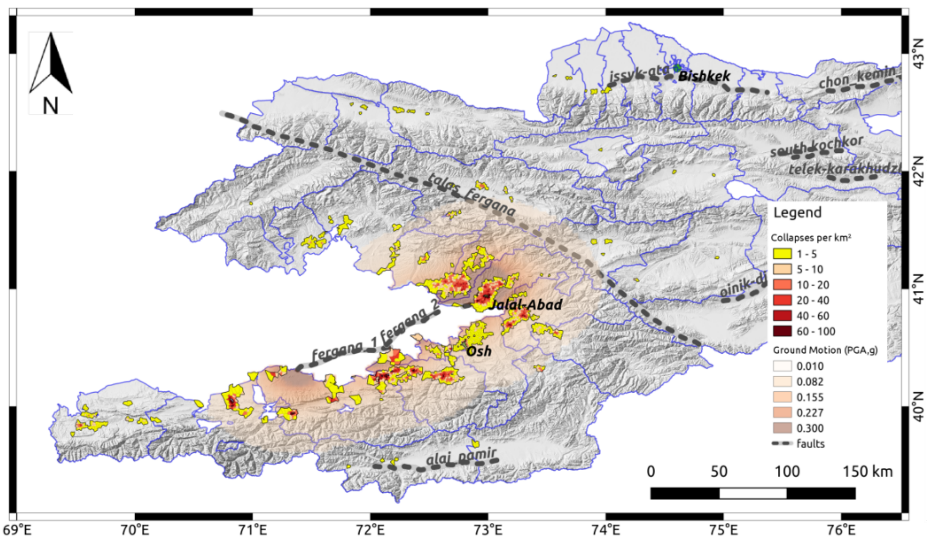

Figure 2 Estimated spatial distribution of residential collapses (EMS-98 damage state D5) per square km, for the Ferghana Valley scenario event (Mw 7.5) with a non-uniform Vs30 assumption from USGS (Arup, 2017a).

The scenario risk results also provided useful evidence to inform post-disaster response in regions and centres of population. For example, a magnitude (Mw) 7.5 event on the Ferghana Valley fault system which would affect the cities of Osh and Jalal-Abad is estimated to cause 5.8 billion USD in economic losses, 17,400 collapses and 5,540 related fatalities for residential buildings (mean results). Refer to Figure 2 above for the spatial distribution of residential building collapses for this scenario. Equally concerning are the estimated losses for critical assets: 286 million USD of economic losses are estimated for schools with 7,160 direct fatalities, 658 million USD for hospitals with 156 fatalities and 28 million USD for fire stations with 8 fatalities. It should be noted that only direct losses have been considered: the potential for secondary fatalities related to earthquake damage to hospitals with compromised functionality, or if emergency personnel are not able to respond after a damaging earthquake event, have not been considered.

The scenario event results also provide useful evidence for priorities and locations for investing in resilience of linear infrastructure such as roads and bridges as well as for planning emergency response. For the Ferghana Valley scenario, for example, economic losses related to permanent ground displacement to roads were estimated to be approximately 0.7 billion USD for roads and 12 million USD for bridges. Locations where severe damage was expected to roads and bridges were the primary route connecting the cities of Jalal-Abad and Bazar-Korgon; this also serves as a cross-border route to the town of Andijan in neighboring Uzbekistan.

Cost benefit analysis

To inform priorities for investment in the seismic risk reduction strategy, selected high level cost benefit analyses were performed for retrofit options for representative construction typologies in each building asset portfolio (residential, schools, hospitals and fire stations). The estimated costs to implement the retrofit options were generally in the order of 40% of the buildings' replacement value. The specific retrofit measures proposed for buildings are described in more detail in the project report (Arup, 2017b). Cost benefit analysis was not performed for bridges due to lack of information on the specific characteristics of bridge construction available for the Kyrgyz Republic.

Methodology

The cost benefit analysis (CBA) was performed considering a remaining building design life of 50 years with a discount rate of 5%[10] . The CBA compared the benefit due to fatalities avoided or reduced economic losses (for "as-built" and "retrofitted" EALs from the probabilistic risk assessment using the OpenQuake engine) due to the improvement in performance of retrofitted buildings with the up-front cost of retrofitting. Only direct losses and fatalities from damage to physical infrastructure were considered; indirect losses such as damage to building contents or disruption were excluded. To be consistent with the seismic risk assessment the CBA calculations were performed for nine combinations of the ground motion prediction equations and soil condition models (Arup, 2017b).

The "as-built" fragility functions used in the risk assessment for the Kyrgyz Republic were derived using the vulnerability index approach proposed by Gulkan et al. (1992). The methodology used to derive fragility functions that account for the effect of different retrofit options on the seismic fragility of a specific building class included the following steps: (a) determine the building capacity that is consistent with the "as-built" fragility functions for the class of interest. Capacity is determined in terms of strength versus ductility (or force versus displacement capacity), usually referred to as a "capacity curve"; (b) estimate the change in the building capacity curve (in terms of enhanced ductility and/or strength) due to a specific retrofit measure and obtain the resulting retrofitted capacity curve; and (c) use these retrofitted capacity curves to obtain the retrofitted fragility functions.

To translate the retrofitted capacity curves into retrofitted fragility functions for different damage states, the methodology proposed by Vamvatsikos and Cornell (2006) was used. This is performed using a software tool SPO2IDA, developed to provide a direct connection between the static pushover (SPO) curve and the corresponding median incremental dynamic analysis (IDA)

[10] The discount rate represents the opportunity cost to invest money in the retrofit measures to determine the present value of future cash flows. In choosing this rate, several factors have been considered: the time period over which it is applied (50 years), the wider risks for the country (political, economic), implementation risk for the investment projects and the predicted growth of the national economy.

results. The median IDA results at specific response limit states were subsequently used to infer the mean parameter of the cumulative lognormal fragility function for the damage states of interest. The same methodology was used to infer the as-built building capacity from the as-built fragility functions. However, because this framework was originally designed to provide building fragility as a function of building capacity and not the opposite, an iterative approach was used to identify the capacity curve that matches the as built fragility most closely. In addition, it is assumed that the lognormal standard deviation of retrofitted fragility functions is equal to those of the corresponding as-built fragility curves. A literature review was conducted in order to identify the effect of each of the retrofit options on the capacity of the corresponding building classes.

Selected Results

In monetary terms, the benefit-cost ratios (BCRs) or present net value of benefits/present net value of costs, did not exceed 1 for the cost benefit analyses performed, except for school buildings in regions such as the Ferghana Valley near Osh and Jalal-Abad, and the southernmost part of the country (the Alaisky region). On the other hand, significant benefits in terms of avoided fatalities were demonstrated: for example, an investment of 60 million USD for retrofitting selected school buildings to maximize limiting loss of life is estimated to avoid 535 fatalities over the 50 year period (or 24% of fatalities expected for the entire school portfolio). Refer to Figure 3 below.

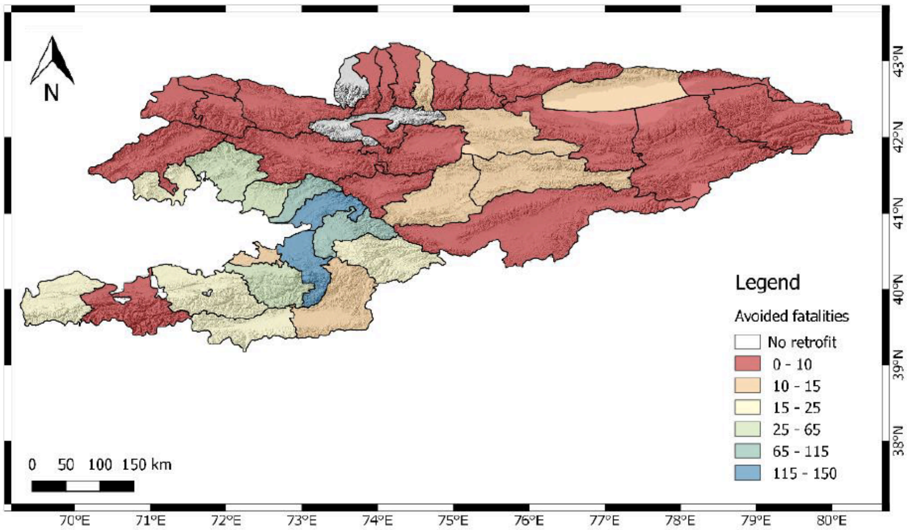

Figure 3 – Rayon-level spatial distribution of avoided fatalities (mean results), for applying proposed school retrofit options that achieves the highest fatality reductions (Arup, 2017b).

For hospital buildings, investing in retrofits (a cost of approximately 750 million USD for the country) is estimated to avoid 140 to 310 direct fatalities over the period (or 56% to 81% of expected fatalities). Although the high level CBA performed was relatively simplistic and only accounted for direct losses, the results provided useful new evidence to make the case for targeted risk reduction by sector and geographic region.

Seismic Risk Reduction Strategy

Adopted Framework for Risk Reduction

The risk reduction strategy and recommendations were made in accordance with the Sendai Framework for Disaster Risk Reduction (UN, 2015) which was formally adopted by the Kyrgyz Republic in 2016. The Sendai Framework is a 15-year, voluntary, non-binding agreement which recognizes that the State has the primary role to reduce disaster risk, but that responsibility should be shared with other stakeholders including local government and the private sector. Its main aim is the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries (UNISDR, 2009).

Methodology

In order to develop a seismic risk reduction strategy to achieve the goals of the Sendai Framework for the Kyrgyz Republic, the following methodology was adopted: firstly, a review of existing institutional, regulatory and financial environment in the country was carried out. This involved an in-depth literature review, review of inputs from key stakeholders and project partners and covered areas such as the legal framework for disaster risk reduction (DRR), built environment codes, standards and regulation, the insurance sector and mechanisms for disaster risk financing. A comprehensive review of past DRR policy and activities in the country and wider region was also carried out to understand gaps and current priorities, lessons learned and opportunities to scale up capacity and implementation of earthquake disaster related risk reduction. A brief overview of the institutional, regulatory and financial environments as well as past DRR activities is presented in this section.

The seismic hazard and risk results including the cost-benefit analyses were used as part of the strategy and recommendations to provide quantitative evidence to incentivize risk awareness, to set priorities for investment and to inform emergency response in post-earthquake scenarios.

A key element throughout the process was stakeholder engagement to understand their priorities as well as ongoing communication on the results and recommendations of the study. This was achieved by appointing a Steering Committee of representative key stakeholders in the country. These included the National Government, the Ministry of Education and Science, the Ministry of Health, the Ministry of Emergency Situations, the Ministry of Finance, Ministry of Transport and Communications and the GOSSTROY (see below). In addition, a number of technical institutes were also represented including the National Statistical Committee, the Institute of Seismology and the Central-Asian Institute for Applied Geosciences (CAIAG).

To communicate the strategy effectively, the recommendations were framed in terms of the Sendai Framework Priorities as well as by sector and tailored for individual stakeholders. Communication and dissemination activities were combined with capacity building workshops for stakeholders in the areas of seismic hazard and risk assessment, risk reduction and seismic retrofitting. This ensured that the results of the wider study and strategy recommendations could be adopted by the Government and other stakeholders and incorporated into longer term efforts to reduce seismic risk in the country. In addition, recommendations for how the study could be integrated into ongoing and future development programmes were provided.

Key Context: the Institutional, Regulatory and Financial Environment

The national government and individual ministries have a leading role in setting strategic goals, the legal framework, execution and funding for disaster risk reduction in the Kyrgyz Republic. The government administration is organized at the national level, oblast level (state or province) plus Bishkek and Osh, rayon level (districts) plus 11 cities with rayon level status and ayil oskhmota (primary territorial level). As the Kyrgyz Republic transitioned away from a system with centralized control based on the Soviet system, local government gained more influence and responsibilities. That said, agencies at local government level still often rely on transfers of funds from central government which can impact funding at a local level for disaster risk reduction and community engagement (World Bank, 2016). DRR in the country is also supported and influenced by international organisations, humanitarian agencies, technical institutes and representatives from civil society (ICF, 2016).

Appropriate regulation of planning, design and construction is a key aspect to reduce risk related to physical infrastructure. In the Kyrgyz Republic, a number of government departments are involved in planning decisions, codes[11]and standards and construction monitoring including the Design Institute, the GOSSTROY and local government (LSGs). Key gaps that were identified include: inadequate funding mechanisms for land use planning, lack of a requirement to periodically update land use plans and zoning maps as well as a lack of capacity and capability in the LSGs for adequate construction monitoring, particularly for smaller residential structures and hence, a lack of proper enforcement. There is also a need to increase training for engineers, construction professionals and community builders on compliant seismic design for new construction and retrofitting of existing buildings (ICF, 2016).

Measures to retrofit and replace highly vulnerable assets can reduce risk but significant residual risk will always remain. To address the residual risk, financing and insurance mechanisms are needed to provide post-disaster funding to aid recovery and reduce economic disruption. The Kyrgyz Republic is especially vulnerable to economic shocks from natural disasters as it has both

[11] Seismic codes have been in place since 1951 (the former Soviet codes) and seismic provisions have been updated in 1991 (SNiP 11-A 12-81*) and in 2009 (KR 20-02:2009).

a high level of risk as well as a relatively low GDP per capita for the region. Currently, insurance is offered for all perils (including from natural hazards such as earthquakes, floods and wind). In 2007, it was reported that individual policies had a very small level of market penetration in the Kyrgyz Republic – for example, 10,000 residential policies country wide or less than 1% of all insurable urban housing (CAREC, 2008). Both lack of skills and capacity in the insurance industry to understand and quantify the levels of natural hazard loss potential from natural hazards, as well as lack of data availability and systematic data collection pose challenges for insurance in the country. Insurer's capital base requirements are very low (0.5 million USD in 2007) and generally reinsurance is not purchased unless required by large commercial clients (NCSD-KR, 2012), which increases the risk of insolvency of insurance companies in the event of a disaster.

Past DRR in the Kyrgyz Republic

To understand previous laws, programmes and actions related to Disaster Risk Reduction (DRR) in the country, a detailed review was carried out ahead of developing the strategy. This identified current gaps and challenges in implementing DRR as well as to collected information from existing databases on infrastructure assets and their vulnerability to natural hazard risk. Figure 4 below summarises key milestones in DRR policy and implementation since the country declared independence.

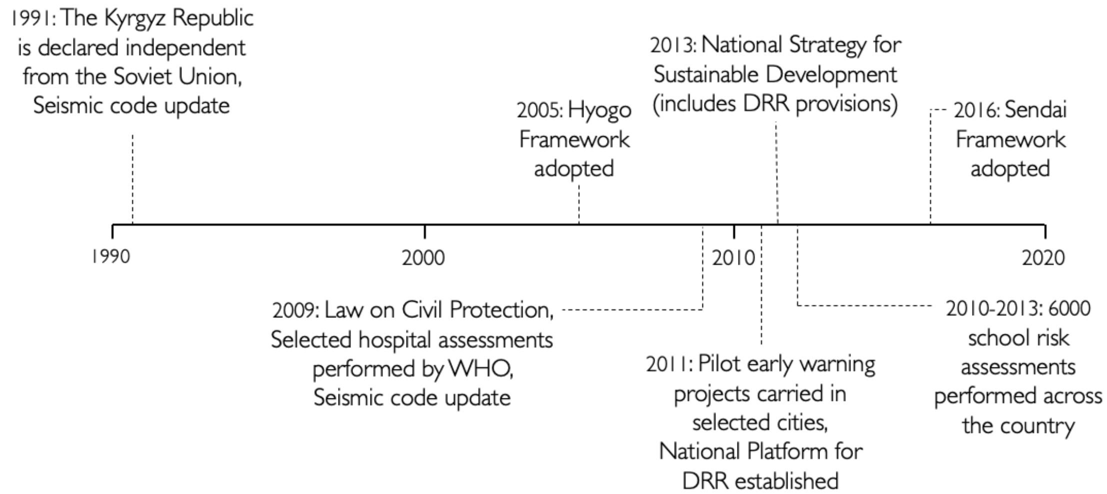

Figure 4 – Key milestones in DRR in the Kyrgyz Republic (ICF, 2016; Sekimov, 2015)

Seismic Risk Reduction Recommendations

Table 1 below highlights key seismic risk reduction strategy recommendations from this study, organized in accordance with the Sendai Framework priorities:

Understanding Risk	**Strengthening Disaster Risk Governance**
Further dissemination and communication should be undertaken to wider stakeholders and the general public to raise awareness of seismic hazard and risk in the country. The understanding of seismic hazard in the country can be improved through further study of active faulting, extending the existing countrywide network of strong ground motion recording instruments and further study of seismic site effects in urban areas. The understanding of exposure and vulnerability of critical assets in the country can be improved through surveys of existing buildings and infrastructure as well as post-earthquake damage and loss surveys. Building upon the current findings and using future updated hazard, exposure and	Approve the 'Law on Seismic Safety' to legally mandate the framework for seismic risk reduction. Finalize the draft '2016-2030 Strategy for the Emergency Protection of the Kyrgyz Republic' taking into consideration the seismic risk results and risk reduction strategy recommendations. Assign roles, responsibilities and funding to support open data on seismic hazard and risk. Increase funding for seismic risk reduction programmes in the country based on the goals of the finalized strategy. Provide capacity and capability in relevant government bodies and institutions to ensure seismic hazard and risk information is used to inform land use planning including aspects related to emergency response.

vulnerability data, more detailed seismic risk assessments can be performed for critical assets. These risk assessments can then inform more detailed sectoral risk reduction plans.	Improve capacity and capabilities of the checking authorities for design and construction generally in addition to improvements for seismic design for new construction and seismic retrofits.
Investment for Improved Resilience	**Enhancing Preparedness for Disasters**
Plan and implement seismic risk reduction programmes with prioritized actions for critical assets. These should be a combination of physical interventions (replacements and retrofits of assets) and soft measures (policies, community engagement and incentives). Produce guidance and carry out training for design professionals on the seismic provisions of the Kyrgyz building codes to improve understanding of the building codes and regulations. Update the seismic codes and improve code provisions related to seismic design and retrofit of buildings and infrastructure. The country-wide seismic hazard map can be used as an input to an updated code hazard map. Improved and up-to-date land use plans which incorporate seismic risk information.	The results of this study should be used to inform updated emergency plans in all sectors. Recommendations by sector are provided but cross-sectoral coordination is strongly encouraged as well as community engagement to communicate emergency plans. The results of this study should be used to identify gaps in emergency response capacity in the country. The government and relevant stakeholders (the World Bank, the State Insurance Organization) should explore disaster risk financing options as well as measures to strengthen the insurance industry. The results of this study can be used to understand the magnitude of expected losses from damaging earthquake events.

Table 1- Key Seismic Risk Reduction Recommendations by Sendai Framework Priority

Detailed seismic risk reduction recommendations are included in the full project report which is available online on the Kyrgyz Republic Geonode (Arup, 2017b). The recommendations cover the following areas and asset categories: the disaster risk management framework (DRM) for the country, understanding seismic risk, the construction and regulatory environment, disaster risk financing and insurance, school buildings, hospital buildings, fire stations, residential buildings, transport infrastructure (roads and bridges) and cultural heritage assets. In addition, key recommendations are provided for each type of stakeholder.

Discussion

Based on a countrywide seismic hazard and risk study and engagement with the World Bank and local stakeholders, a comprehensive seismic risk strategy has been proposed for the Kyrgyz Republic. The main aim is to provide guidance to the Government of the Kyrgyz Republic and other key stakeholders to prioritise risk reduction actions and investment that will save lives, reduce damage to critical buildings and infrastructure and reduce the economic losses caused by earthquakes in the country.

Comprehensive seismic risk reduction strategies at city, regional or country scale are rare. Strategies often are not cross sectoral, only address post disaster response or do not cover the technical, hard measures such as retrofitting in combination with the societal and policy aspects (JICA, 2009; Gilani et al., 2015). In accordance with the Sendai Framework, the strategy and recommendations for the Kyrgyz Republic covered technical aspects such as risk assessment and engineering measures to improve resilience as well as the role government institutions at all levels and communities to carry out successful DRR. It was developed in consultation with key stakeholders in the country. The approach was informed by a deep understanding of the current institutional, regulatory and financial environment in which DRR is implemented to ensure recommendations were appropriate, build on past experience and targeted gaps. Recommendations and priorities were based on the quantitative evidence on seismic hazard and risk study component which served to both provide a strong incentive to reduce the risk and also to focus efforts on the most critical assets and at-risk cities and regions in the country. For example, cost benefit analyses gave evidence to justify a new geographic focus for investment, in the Ferghana Valley, in addition to the capital city Bishkek, particularly for schools and hospitals.

Disaster risk reduction is a continuous process: the intention of the strategy is that local stakeholders with the support of international organisations such as development banks and humanitarian agencies can continue to adapt the strategy as they carry out recommendations and gain more knowledge about the seismic risk in the country. Only indirect losses due to loss of contents, cost of disruption and indirect fatalities caused by loss of service were taken into account, especially for critical facilities. It is recommended that more detailed CBA is performed in future that takes these factors into account to strengthen the case for investing in retrofits – both in terms of economic benefits as well as reduction in fatalities. In addition, limited information was provided on the exposure and vulnerability of some asset categories such as health care facilities and bridges which increased the uncertainty in risk results and limited the scope of the cost-benefit analyses performed. The strategy should also be integrated into the Kyrgyz Republic's wider DRR strategy that addresses other hazards such as flooding, landslide and environmental hazards.

Further Developments

Since the seismic risk reduction strategy and recommendations were presented to the Government and other key stakeholders in 2017, the results and recommendations have already been adopted in several large government initiatives in partnership with the World Bank including a countrywide safer schools programme and measures to effectively implement a mandatory disaster insurance program for private residential property (World Bank, 2019b).

Acknowledgements

The authors wish to thank the Government of the Kyrgyz Republic, the World Bank and the Global Facility for Disaster Risk Reduction (GFDRR) for their support with the undertaking of this project, and permission to publish the results.

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